An evaluation of alternative measures of accessibility for investigating potential 'deprivation amplification' in service provision

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Conflict of Interests

None declared.

Abstract

Studies examining potential social inequities in resource distribution have tended to adopt relatively unsophisticated measures of service supply such as those derived from proximity measures or counts of facilities within given time/distance thresholds. Often such measures do not take into account potential demand for services and the implications this has for understanding socio-spatial patterns in service provision. In this paper, a comparison is made between spatial patterns of accessibility to a range of services by socio-economic gradients for a subset of 'traditional' measures of provision with trends revealed by the use of floating catchment area (FCA) methods. Statistical and visualisation tools are employed to examine variations in access scores across deprivation quintiles for all the services included in an accessibility 'domain' of a policy-relevant Index of Multiple Deprivation. Findings suggest that, whilst the use of proximity or cumulative opportunity approaches consistently point to greater levels of access in more deprived areas, results from the application of FCA methods point to non-linear trends in the relationship between access and socio-economic patterns of deprivation for some key services. This suggests that the use of measures that account for both potential service demand and distance-decay effects demonstrate patterns that are at odds with those revealed by the use of 'traditional' metrics. We conclude by highlighting prospective implications of using different methodological approaches to measuring spatial patterns of accessibility for understanding socio-economic patterns in service provision, and the broader policy relevance of encapsulating potential service demand within socio-spatial investigations of levels of access.

Keywords: Service provision; Socio-economic patterns; Accessibility measures; Two-step floating catchment area (2SFCA) methods; Sensitivity Analysis

1. Introduction

Spatial accessibility is one of a number of recognised barriers to wider considerations of access; the others being availability, affordability, acceptability and accommodation (Penchansky and Thomas, 1981). It refers to a consideration of both the availability of a service (e.g. the number of available supply points) and the geographical distances involved in accessing a service (often measured by the travel cost between the service delivery point and potential users; Guagliardo, 2004). From a policy perspective, the measurement of ‘potential’ spatial accessibility (hereafter ‘accessibility’), which refers to prospective levels of accessibility based on the analysis of spatial patterns in physical access to services (rather than actual patterns in service utilization; so called ‘realized’ accessibility), can inform policymakers of potential disparities in provision by identifying areas where levels of accessibility are poor and targeted interventions needed (Joseph and Phillips, 1984). Such an approach is particularly common in the context of healthcare where, for example, levels of accessibility to primary care physicians have been estimated to highlight potential inequalities in healthcare delivery (Luo, 2004). An important area of study, inequitable levels of access can have important effects on health outcomes – for example, lower levels of access to cancer screening facilities has been associated with an increased risk of late-stage cancer (Wang et al., 2010).

Over the last decade there has been a proliferation of Geographic Information System (GIS)-based studies that have investigated spatial patterns in service accessibility across various geographical and socio-spatial contexts (e.g. Macintyre et al., 2008; Pearce et al., 2007; Pearce et al., 2008; Bauer et al., 2017). Many such studies examine accessibility to health promoting (or so-called ‘salutogenic’) services, such as sports facilities (e.g. Ferguson et al., 2013; Ogilvie et al., 2011; Lamb et al., 2010; Lamb et al., 2012; Billaudeau et al., 2011; Higgs et al., 2015), green spaces (Higgs et al., 2012) or healthy food opportunities (Smith et al., 2010), as part of wider studies that explore the interaction between compositional (people) and contextual (place) factors and their impact on health outcomes (Macintyre et al., 1993). ‘Deprivation amplification’ is a hypothesis which proposes that “...poorer neighbourhoods will usually have poorer access to health promoting resources and more exposure to health damaging ones...” (Macintyre et al., 2008: 901), and has tended to form the conceptual basis of these and similar investigations. To date, however, there has been mixed support for the ‘deprivation amplification’ hypothesis with some findings suggesting a less uniform association between patterns of service accessibility and levels of area deprivation. This has led to refinements of the concept to suggest that “[t]he spatial distribution of resources by deprivation may vary between types of resource, geographical location..., countries, and time periods” (Macintyre, 2007: 902). In this paper, we posit that a further component, namely the methodological approach used to measure accessibility, may also impact on such trends and can be expected to influence investigations into potential deprivation amplification in resource access.

Studies examining associations between levels of service accessibility and indicators of area level deprivation have tended to rely on relatively simplistic approaches to measurement, such as population-provider ratios (PPRs; Cummins et al., 2005), average or median distances (Pearce et al., 2008; Smith et al., 2010), shortest distance to nearest service (Macintyre et al., 2008), or number of facilities available within a specified time/distance threshold (Lamb et al., 2012; Ogilvie et al., 2011; Ferguson et al., 2013). Whilst each of these approaches has their respective strengths, a major contention of this paper is that most fail to consider important interactions between supply and potential demand, which could have wider implications for studies of socio-economic disparities in provision. In particular, we argue that it makes more sense when investigating levels of service accessibility to measure both supply and demand and their interactions in instances where, for example, good geographical access to services may be undermined by high levels of demand in the immediate vicinity of services, or vice versa. In this context, approaches to accessibility measurement that neglect potential demand will only provide partial insights into spatial patterns in levels of access.

The purpose of this paper is to examine the degree to which associations between levels of access and socio-economic deprivation are dependent on the methodological approach to accessibility measurement. This is achieved through a comparison of trends revealed using traditional approaches to accessibility measurement (PPR, minimum travel time, and cumulative opportunity) with levels of access calculated using floating catchment area (FCA) methods. Research intent on directing policy must be based on the most up-to-date techniques. In the context of measuring access, FCA-based measures are assumed to be more spatially advanced than 'traditional' methods because they potentially enable more nuanced patterns of access to be obtained that account for the interactive effects of supply capacity, demand volume, and travel distance/time. In this paper, we aim to build upon previous studies which have examined implications arising from different approaches to measuring accessibility (e.g. Neutens, 2015; Apparicio et al., 2017; DeWulf et al., 2013) by considering these effects at national level, for multiple services, and in terms of associations with socio-economic variations in deprivation.

2. Approaches to measuring spatial accessibility

2.1. 'Traditional' approaches

Many methodological approaches have been used in a GIS environment to estimate potential levels of service accessibility (for reviews, see Neutens, 2015; Wang, 2012; Higgs, 2004; Yang et al., 2006; Paez et al., 2012). Container and distance-based measures are the 'traditional' approaches to measuring potential accessibility. The former is based on simple supply-to-demand ratios (or 'PPRs') computed inside areal boundaries such as administrative units; the latter measure a time or distance to reach a service from a specified point of origin (the 'demand centre'). The application of a container-based approach, for example, could include calculating the ratio of primary healthcare physicians within a given area relative to the number of potential patients, whilst a distance-based approach might compute the shortest distance from the population-weighted centroid of a census tract (or similar) to the nearest available physician (Dewulf et al., 2013). In the absence of more detailed data on residential location, demand centres are commonly representative of the centroid of a spatial unit; a point which can be population-weighted and/or further refined through land use maps (Apparicio et al., 2017).

A strength of these measures is that they are easily computable with basic GIS capabilities and are also straight forward to interpret as they are based on absolute units (Neutens, 2015). Although both have limitations that, arguably, make them less appropriate for measuring accessibility at detailed geographical scales. For instance, container methods neglect possible cross-border flows, assuming that users always remain inside their respective boundaries and do not, regardless of geographical proximity, access services in neighbouring areas. This approach also assumes equal access across the entirety of the container regardless of actual proximity (Luo and Qi, 2009). In a similar vein, distance methods using Euclidean (straight-line) or Manhattan measures do not reflect ‘real-life’ travel based on actual road networks, with speed limits and other relevant travel impedances. Whilst advancements in GIS routing algorithms coupled with increased availability of detailed transport data have ameliorated such criticisms, these metrics still fail to consider any implications arising from local demand levels, and neglect the individual agency of service users by assuming that travel distance/time is the only relevant factor mitigating service choice, rather than, say, service quality or personal preference.

To lessen the deficiencies of both methods, by utilising the evolving functionality of a GIS, some studies have used a combination of both container and distance approaches. They adjudge a ‘cumulative opportunity’ for accessing a service by placing a buffer around each demand centre and summing the number of supply points within this catchment. Such buffers can be based on circles of different radii or use varying network travel times/distances. For example, Ferguson et al (2013) examined accessibility to physical activity facilities by car and bus using cumulative opportunity recorded in 10, 20 and 30-minute travel time buffers based on a network model of mainland Scotland. Dewulf et al (2013) used a similar approach in their analysis of primary care accessibility in Belgium, albeit applying distance buffers of 5km and 10km respectively. The main advantage here is that the movement of service users is not unrealistically constrained by abstract areal boundaries, and nor is accessibility measured solely by the closeness of a single service supply point. However, these strengths are tempered by a failure to address potential demand implications in the cumulative opportunity calculation.

2.2. Floating catchment area (FCA) techniques

A derivative of the geographical gravity model, FCA spatial accessibility models can be considered an enhancement on the traditional metrics previously discussed, primarily because they incorporate elements of both supply-to-demand ratio, cumulative opportunity and travel cost in their outputs (Luo and Wang, 2003). In the two-step FCA (2SFCA) specification, a maximum travel threshold is set (using either time or distance) which then determines a catchment area around each service supply point – for example, a 500m travel radius around each sports facility site (Higgs et al., 2015). A supply-to-demand ratio is then determined from the available supply capacity at this point relative to the number of potential users that fall inside its catchment. In step two, a catchment of equal distance (or time) is placed around each demand centre. A final 2SFCA score is recorded as the sum of the supply-to-demand ratios of all service provision points that fall inside this catchment. The 2SFCA score equates to the relative share that each individual has of the total service capacity if restricted to travelling within reasonable proximity of their respective demand centre. The main advantages of 2SFCA are that it allows for the consideration of cross-border factors (unlike the traditional container method users are not confined to arbitrary predetermined spatial boundaries), that it considers the balance of supply and demand arising in the localised neighbourhood, and that it is responsive to cumulative opportunity. Moreover, where detailed provider or population data are available, further refinements to the FCA calculation are possible. For example, examining the number of available hospital beds (supply-side capacity) relative to the proportion of residents with serious health conditions (demand-side volume).

However, while an advancement on traditional accessibility measures, FCA techniques are not without criticism. The use of overlapping catchment areas, it is suggested, could result in an overestimation of local service demand, leading to potential biased supply-to-demand ratios (Neutens, 2015). Its reliance on subjectively defined catchment sizes can also be problematic, particularly when estimating accessibility across different geographical settings (see McGrail and Humphreys, 2009; 2014). However, this is often unavoidable due to a lack of any data on the time/distance that users are prepared to travel to access services and can be remedied to a degree through sensitivity analysis of findings based on multiple time/distance thresholds (Higgs, 2004). A primary limitation of the 2SFCA approach is its assumption that persons in a given catchment have equal access to services regardless of variations in their proximity (McGrail, 2012). This last criticism is addressed by the enhanced two-step floating catchment area (E2SFCA) specification, which uses a weighting function that decreases as supply points move further away from demand centres (Luo and Qi, 2009). Whilst different weighting functions can be applied, a linear-decay function that decreases uniformly is often considered the most appropriate option, particularly if relevant information concerning user preferences or behaviours are unavailable.

Advancements in the field of spatial accessibility metrics, particularly in the form of FCA techniques, have led to this approach becoming widely adopted in primary healthcare studies (Langford et al., 2016; McGrail and Humphreys, 2009; McGrail and Humphreys, 2014; Higgs et al., 2017; Luo and Wang, 2003: Luo and Qi, 2009; Bauer et al., 2017), and other application areas such as childcare (Fransen et al., 2015; Welsh Government, 2017), public health (Dai and Wang, 2011), transport (Langford et al., 2012), and leisure (Higgs et al., 2015). Whilst the potential implications of employing different methodological approaches to accessibility measurement on levels of access have been highlighted previously (Talen and Anselin, 1998; Kim and Nicholls, 2016; Apparicio et al., 2007), very few studies to date incorporated FCA techniques within such comparisons (see Apparicio et al., 2017; Dewulf et al., 2013) or within investigations into associations between accessibility and area deprivation (Higgs et al., 2015).

3. Methodology

3.1. Study Area

Wales is one of the four countries that constitute the United Kingdom (UK). It has an estimated population of approximately 3 million residents, making it the third most populated UK country and responsible for 4.7% of the total UK population (Office for National Statistics [ONS], 2017a). Within Wales the majority of the population reside in the south, in the main cities of Cardiff (the capital of Wales, n=361,468), Swansea and Newport, as well as within the surrounding Welsh valleys (areas characterised by ex-coal mining towns and villages) (ONS, 2017b). Based on the UK geographical classification of lower super output areas (LSOAs, n=1,909), which have average populations of approximately 1,600 residents, 68.3% of Welsh LSOAs are classified as urban (ONS, 2017c). A more detailed breakdown of the rural-urban geography of Wales is provided in Table 1. Population densities and deprivation levels among Welsh LSOAs are presented in Figure 1. Overall, Wales has an estimated population density of 150.1 people per km^2 (Stats Wales, 2016) – although much variation is evident when examined across smaller spatial scales. Broadly speaking, less deprived LSOAs tend to be situated in the East, near the Wales-England border. Wide variations in geographical and topographical characteristics, and a rich availability of open-source datasets, mean that Wales is well suited to act as a test-bed for examining associations between deprivation and alternative service accessibility metrics at national level.

Table 1: Rural urban classification of Welsh LSOAs

RUC11CD	RUC11NM	% Population	% Area (km^2)	Persons per km^2
C1	Urban city and town	66%	10%	6.38
C2	Urban city and town (sparse)	2%	<1%	4.26
D1	Rural town and fringe	13%	7%	1.96
D2	Rural town and fringe (sparse)	4%	4%	0.97
E1	Rural village and dispersed	7%	23%	0.30
E2	Rural village and dispersed (sparse)	8%	55%	0.14

RUC11CD = Rural Urban Classification code; RUC11NM = Rural Urban Classification name

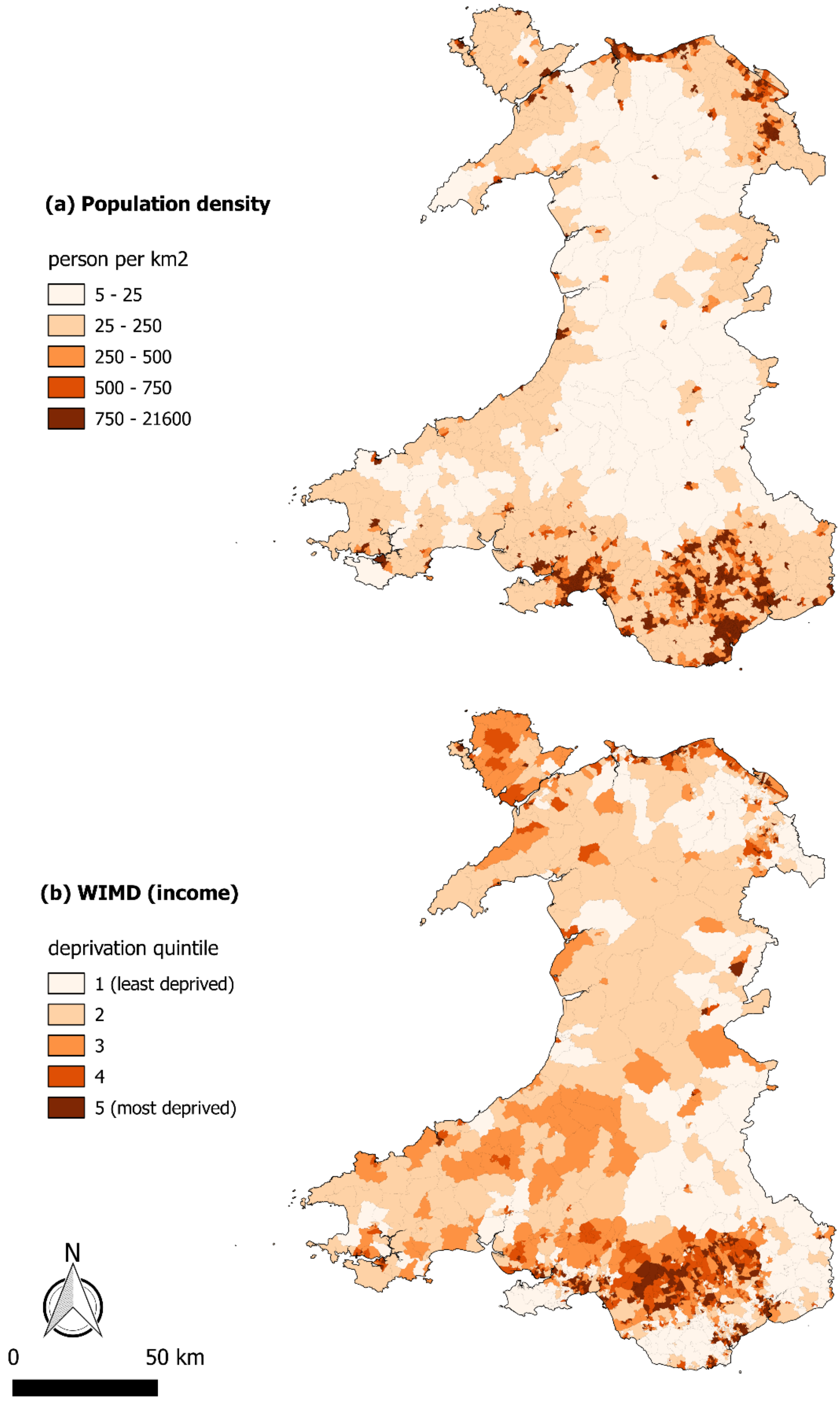


Figure 1: Population density and deprivation level of Welsh LSOAs

3.2. Data

For this study, the precise locations of service supply points were obtained for the following nine services; general practice (GP) surgeries, pharmacies, food shops, public libraries, leisure centres, petrol stations, post offices, primary schools, and secondary schools. The decision to include these particular services within our analysis was predicated on their being recognised by Welsh Government as services "…necessary for day-to-day living" and as such are currently included in the geographical access to services domain of its national deprivation index; the Welsh Index of Multiple Deprivation (WIMD; Welsh Government, 2014: p.20). Access to similar services forms a component of deprivation indices defined independently for England, Northern Ireland, and Scotland (Department for Communities and Local Government, 2015; Northern Ireland Statistics and Research Agency, 2017; Scottish Government, 2016). Information on the locations of all GP surgeries (n=453)[1], primary schools (n=1,093) and secondary schools (n=205)[2] were obtained from the Welsh Government. A database of services supplied by Ordnance Survey (accessed through Digimap)[3] was used to collect information regarding post offices (n=807), public libraries (n=207), petrol stations (n=540), and food shops (n=3,444); the latter of which were classified as any shop where bread and milk could be purchased. The locations of all pharmacies (n=714) were obtained from National Health Service (NHS) sources, and leisure centres (n=195) from a national database of sports facilities supplied by Sport Wales. Supply points for each service were geocoded using an online service[4] based upon latest UK postcode and input to a GIS (namely, ArcGIS™ v10.4; ESRI, 2015). As a proxy for residential location, and to represent demand centres, population-weighted centroids were obtained from the ONS Open Geography Portal[5]. Population counts from the 2011 UK Census were obtained from Nomis[6] and used as proxies for potential levels of service demand in the FCA calculation. Digitised boundary data were obtained from the UK Data Service[7].

3.3. Accessibility measures

In total, five different approaches were used to estimate levels of access to each of the nine services from all 1,909 LSOA demand centres; PPR, minimum travel time (in minutes), cumulative opportunity, 2SFCA and E2SFCA. As evident from Table 2, these particular metrics were selected because they represent a progression in level of sophistication to accessibility measurement.

[1] http://gov.wales/statistics-and-research/general-medical-practitioners/?tab=previous&lang=en
[2] http://gov.wales/statistics-and-research/address-list-of-schools/?lang=en
[3] http://digimap.edina.ac.uk/
[4] https://www.doogal.co.uk/
[5] http://geoportal.statistics.gov.uk
[6] https://www.nomisweb.co.uk/
[7] https://borders.ukdataservice.ac.uk/

Table 2: Methods breakdown of included approaches to accessibility measurement

Metric	Components of spatial accessibility	Example
Population-provider ratio (PPR)	Supply capacity + demand volume (computed within an arbitrary reference zone)	Number of GP surgeries per capita in a given area (e.g. census tract)
Minimum travel time/distance	Travel impedance only (time/distance)	Travel time/distance to the nearest GP surgery from a demand point (e.g. census tract centroid)
Cumulative opportunity	Travel impedance + supply capacity	Number of GP surgeries within a specified time/distance from a demand point (e.g. within a 15-minute drive)
Two-step FCA (2SFCA)	Supply capacity + demand volume (reference zone defined by a travel limit)	Numbers of GPs or GP surgeries that can be reached locally per head of population
Enhanced two-step FCA (E2SFCA)	2SFCA + internal distance decay function	Numbers of GPs or GP surgeries that can be reached locally per head of population within travel time thresholds whilst accounting for the influence of distance decay

All accessibility measures were calculated based on private transport only using a road network constructed from Ordnance Survey ITN layer data (Ordnance Survey, 2015) and the network analyst extension available in ArcGIS^{TM}. Levels of accessibility based on other means of transport (e.g. public bus or train, bicycle, or foot) were not computed due to a lack of available data on possible routeways and timetables at the all-Wales level. With the exception of PPR and minimum travel time approaches, a maximum threshold distance representing a 15-minute drive time was placed around each demand centre in order to constrain the supply-side variables included within the network model. The selection of a 15-minute threshold was a pragmatic choice forced upon us by a lack of any real evidence regarding actual times that service users are prepared to travel to access amenities in the UK. For the purpose of comparison, and to test the sensitivity of estimated patterns of accessibility to varying travel time thresholds, the E2SFCA-derived scores were also computed using five, ten, and thirty-minute thresholds. A thirty-minute threshold was considered an appropriate cut-off based on evidence that residents of almost every LSOA in Wales can undertake a two-way journey by car to each of the selected services in under thirty minutes; around 88% in under ten minutes and 98% under twenty minutes (Welsh Government, 2015, p.9) This was used to justify the time thresholds used in this study. The computational steps used to calculate each of the accessibility metrics are now presented in turn.

Population-provider ratio (PPR)

For each area a, a PPR Z_a^P was measured as the total supply volume S_j divided by the total population P_a (equation 1). To make the PPR scores more meaningful, a multiplier was used to create PPRs per 10,000 population.

$$Z_a^P = \sum_{j \in a} \frac{S_j}{P_a} \qquad (1)$$

Minimum travel time

Minimum travel time Z_k^M was measured as the shortest journey time d from each demand centre k to the nearest service supply point j (equation 2):

$$Z_k^M = \min\left|d_{kj}\right| \qquad (2)$$

Cumulative opportunity

Cumulative opportunity Z_k^C was measured as the sum of supply points S_j that fall within the designated maximum travel time/distance threshold d_0 from demand centre k (equation 3):

$$Z_k^C = \sum_{j \in (d_{kj} \leq d_0)} S_j \qquad (3)$$

Two-step floating catchment area (2SFCA)

In step one of the 2SFCA algorithm (equation 4), the availability of a service at provision point j is determined by a supply-to-demand ratio using supply volume S_j and the sum of all demand centre populations P_k within time/distance threshold d_0.

$$R_j = \frac{S_j}{\sum_{k \in (d_{kj} \leq d_0)} P_k} \tag{4}$$

In step two (equation 5), for each demand centre k an 2SFCA score is computed as the sum of all supply-to-demand ratios situated inside the designated time/distance threshold d_0.

$$A_k = \sum_{j \in (d_{kj} \leq d_0)} R_j \tag{5}$$

Enhanced two-step floating catchment area (E2SFCA)

The E2SFCA specification (equations 6-8) uses the same computational steps at the 2SFCA albeit with the inclusion of a geographical weighting function W_{kj} in steps one and two based on the distance between supply and demand. In this study, a simple linear distance-decay function was used to compute the weighting factors.

$$R_j = \frac{S_j}{\sum_{k \in (d_{kj} \leq d_0)} P_k W_{kj}} \tag{6}$$

$$W_{kj} = \frac{(d_0 - d_{kj})}{d_0} \quad if \quad d_{kj} \leq d_0 \tag{7}$$

$$W_{kj} = 0 \qquad otherwise$$

$$A_k = \sum_{j \in (d_{kj} \leq d_0)} R_j W_{kj} \tag{8}$$

To improve spatial accuracy, 2SFCA and E2SFCA scores were first calculated at the highest possible spatial resolution (i.e. UK census output areas), with LSOA-level scores for each service derived by taking the population weighted mean score of all output areas that fall within these respective boundaries.

3.4. Statistical Analysis

Using GP surgeries as a case study service, Kendall's tau-B correlation coefficients (a non-parametric measure of correlation between two ranked variables) were first calculated to examine strengths of associations between accessibility scores derived using the different methodologies. Variations in these scores were then examined spatially. An indicator of spatial autocorrelation, the Moran's I statistic was also calculated in order to highlight the extent of spatial clustering of similar values (Moran, 1950). Associations between access and deprivation levels were then analysed for all services to examine the extent of agreement between the different metrics regarding the socio-spatial distributions of service provision in Wales based on the income domain of the 2014 WIMD (Welsh Government, 2014). Similar to other studies that have utilised IMDs while examining associations between access and deprivation (e.g. Ogilvie et al., 2011), the rationale for using the income domain of WIMD is that the overall IMD contained an accessibility domain that could be collinear with some of our computed accessibility measures. Based on the percentage of the Welsh population receiving income related benefits, tax credits, or with an income 60% below the median level, or whom qualify as a supported asylum seeker, the income domain accounts for 23.5% of the overall deprivation index (Welsh Government, 2014). Sensitivity of E2SFCA-derived access scores to different travel time thresholds were tested for each service by examining associations with both deprivation and rural-urban geography. The decision to test the latter was based on suggestions within the empirical literature that varying catchment sizes may be required when computing levels of access across rural-urban divides (McGrail and Humphreys, 2014; Luo and Whippo, 2012). All cleaning and statistical analysis of data was undertaken in R v3.4.1 (R Core Team, 2017). Maps were constructed in QGIS v2.18 (Quantum GIS Development Team, 2017).

4. Results

4.1. Accessibility to GP surgeries: a case study

Correlation coefficients for associations between each of the five accessibility metrics are presented in Table 2. As to be expected, PPR, cumulative opportunity, and FCA-based metrics were inversely related with minimum travel time. This is because higher scores equate to greater levels of accessibility in supply-based metrics, whilst shorter travel times represent better accessibility in a proximity-based metric. Overall, correlations between the different metrics were generally poor with the exception of moderate strength associations identified between the two FCA-based approaches (tau = 0.43, $p<0.001$)

and between PPR and minimum travel time (tau = -0.42, p<0.001). This is not unexpected given the similarity between 2SFCA and E2SFCA methodologies and given that it may be reasonable to assume that in rural LSOAs minimum travel times may be relatively high and levels of service provision per head relatively poor.

Table 3: Associations between accessibility metrics for access to GP surgeries

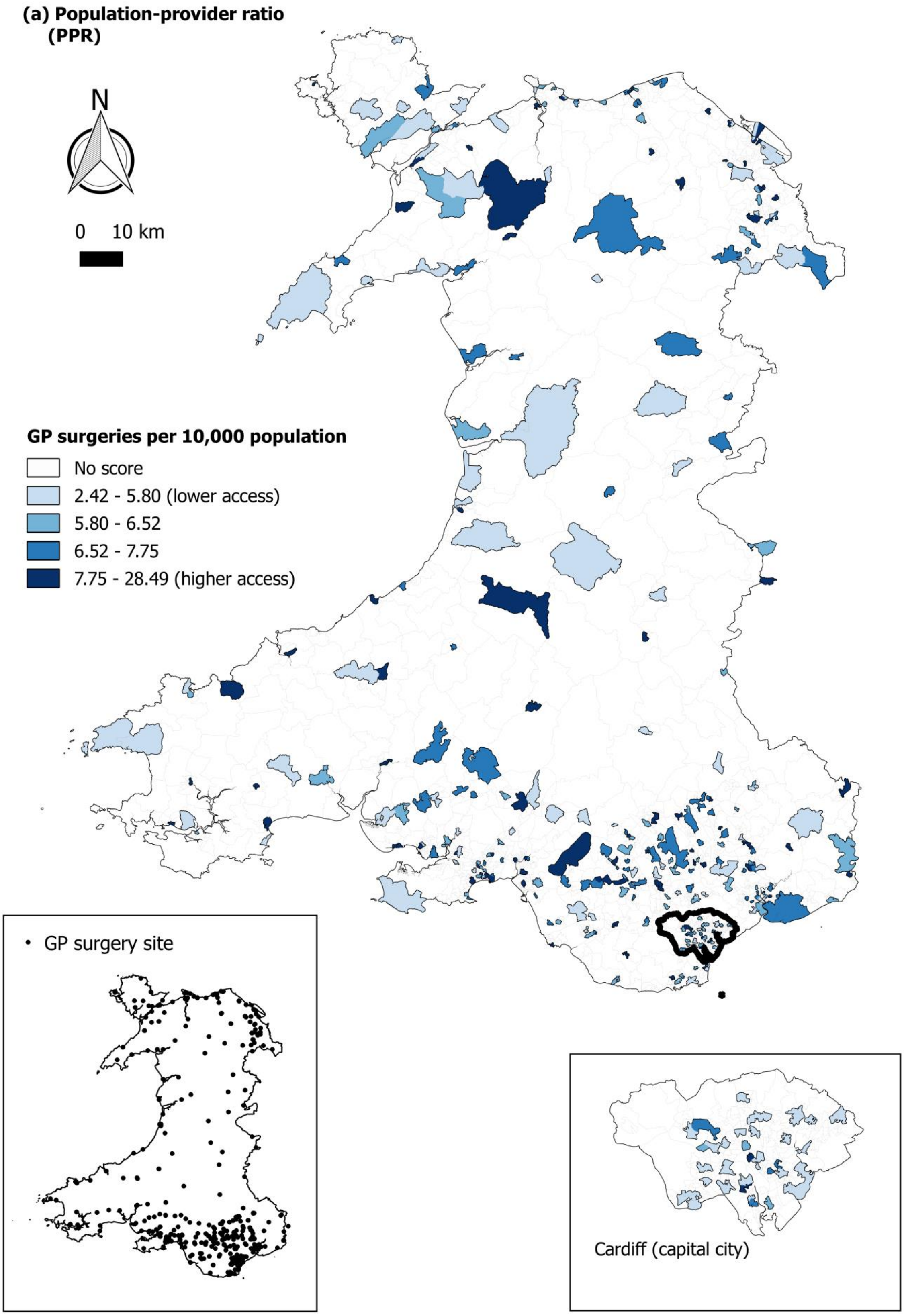
		1	2	3	4	5
1	PPR	1				
2	Minimum travel time	-0.42	1			
3	Cumulative opportunity	-0.01	-0.19	1		
4	2SFCA	0.04	-0.08	0.22	1	
5	E2SFCA	0.15	-0.28	0.09	0.43	1

Note: Kendall correlation coefficients

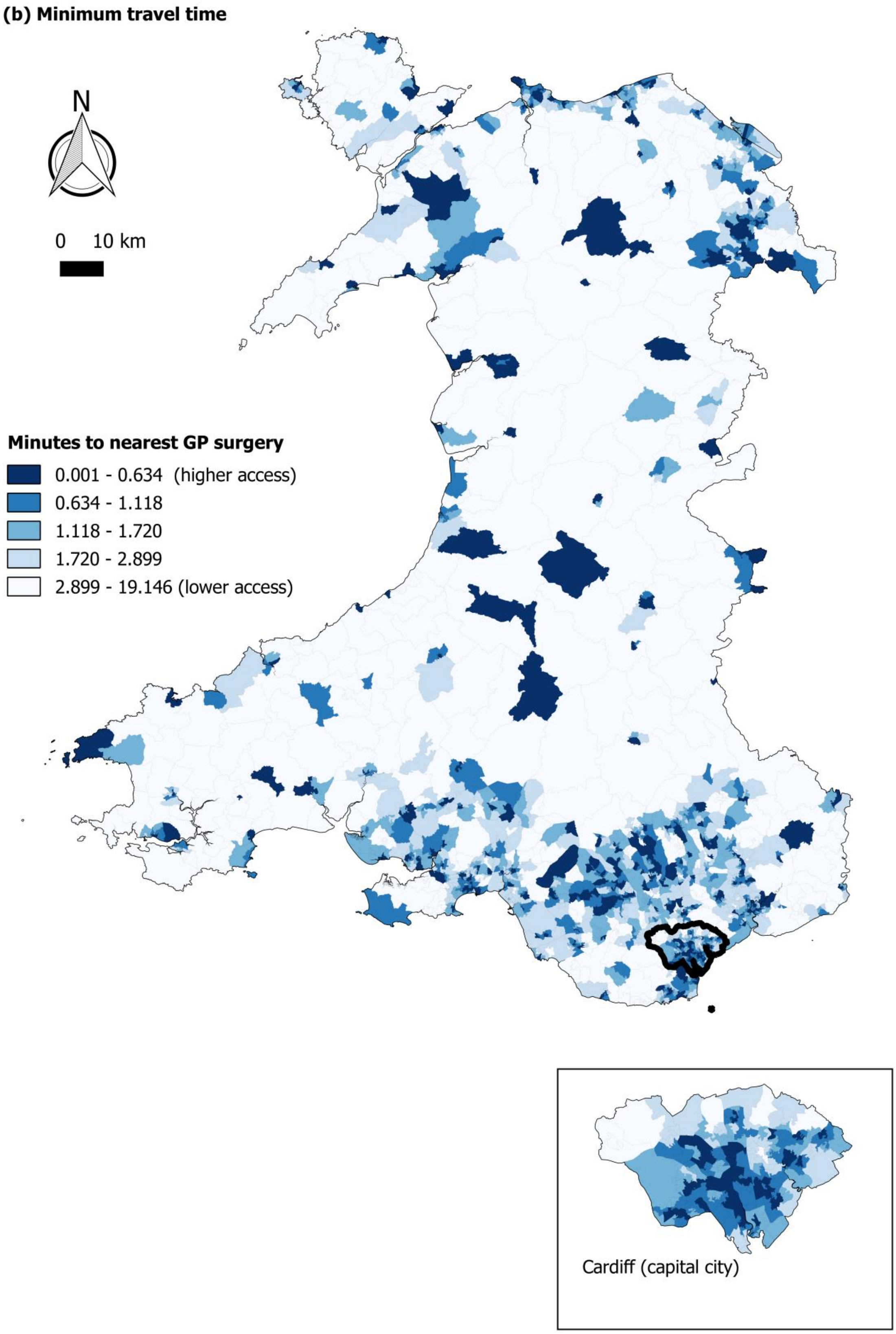
The spatial distribution of GP surgeries across Wales is presented in the bottom left-hand corner of Figure 2a. Unsurprisingly, most GPs are situated in and around the major urban areas of Cardiff and other urban conurbations in South Wales as well as urban areas bordering England in the north east. Spatial patterns in levels of access to GP surgeries according to each of the different accessibility metrics are presented in Figures 2a-e; the darker the shading the greater the level of access.

As expected following the results of the correlation analysis (Table 3), Figures 2a-e further support the striking contrasts in estimated levels of access that can be obtained from these different methodologies. For example, examination of spatial patterns based on minimum travel time or cumulative opportunity (Figures 2b and 2c) measures suggests that such approaches may be biased in favour of urban LSOAs. This is particularly evident with regards to cumulative opportunity, where the highest levels of accessibility to GP surgeries were reported for LSOAs in and around Cardiff, as well as, to a lesser degree, other large urban areas. In comparison, accessibility estimated using FCA-based measures appear to offer some more nuanced patterns of scores that better account for the population distribution of Wales, shown in Figure 1a.

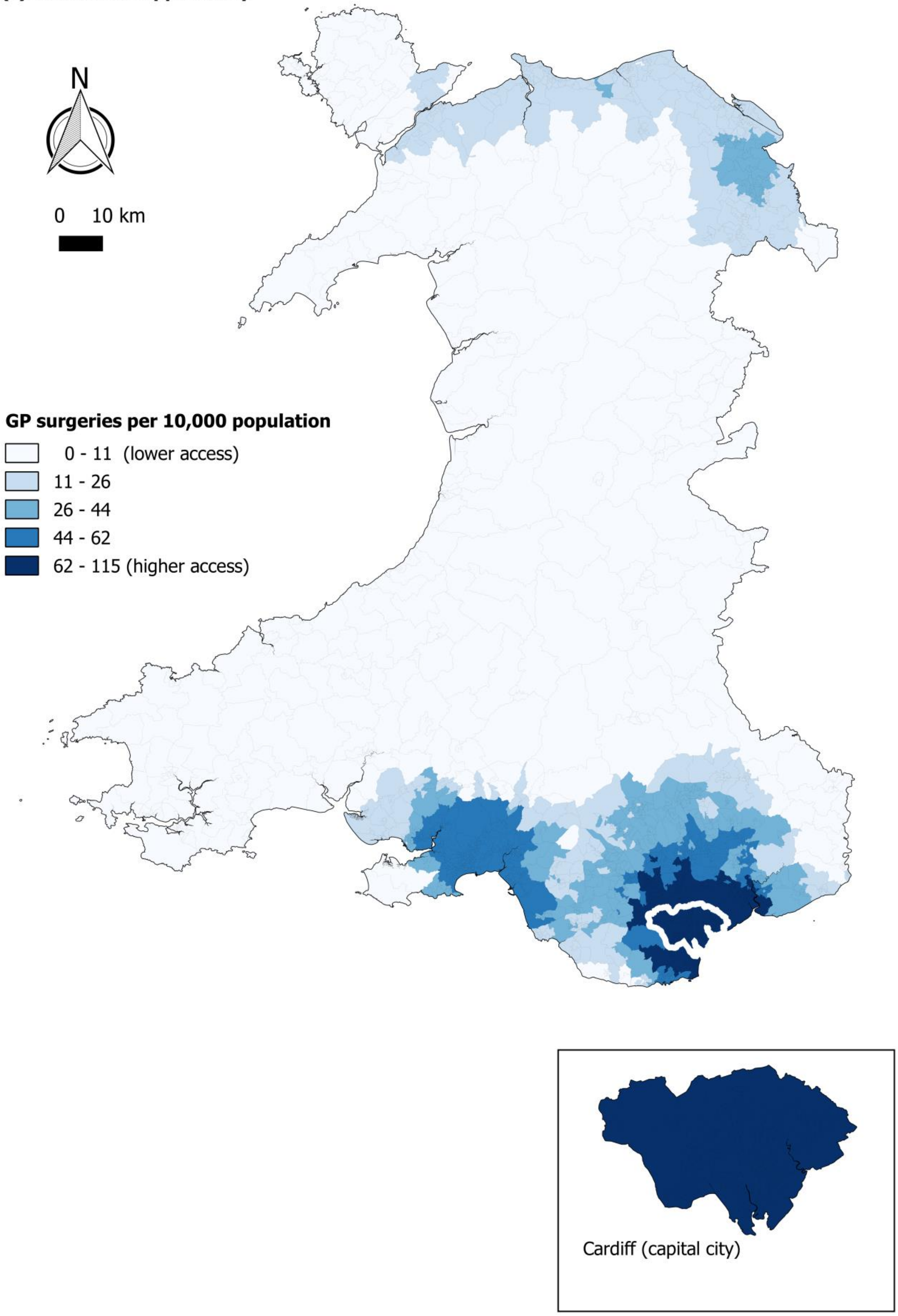
As revealed by the spatial patterns seen in Figures 2a-e, the cumulative opportunity metric was found to exhibit the greatest degree of spatial clustering based on Moran's I (I = 0.973, p<0.001), followed by 2SFCA (I = 0.663, p<0.001), E2SFCA (I = 0.565, p<0.001), and minimum travel time (I = 0.509, p<0.001) measures. No evidence of spatial clustering of PPRs was identified. In addition, a major limitation of the PPR approach to accessibility measurement is immediately evident within Figure 2a. Here only LSOAs containing GP surgeries are deemed to have any level of access, meaning that a high proportion of LSOAs are deemed to have no access at all. As previously suggested, this measure is therefore problematic when applied at fine spatial scales as it takes no account of inevitable cross-border flows of patients accessing primary care within neighbouring LSOAs.

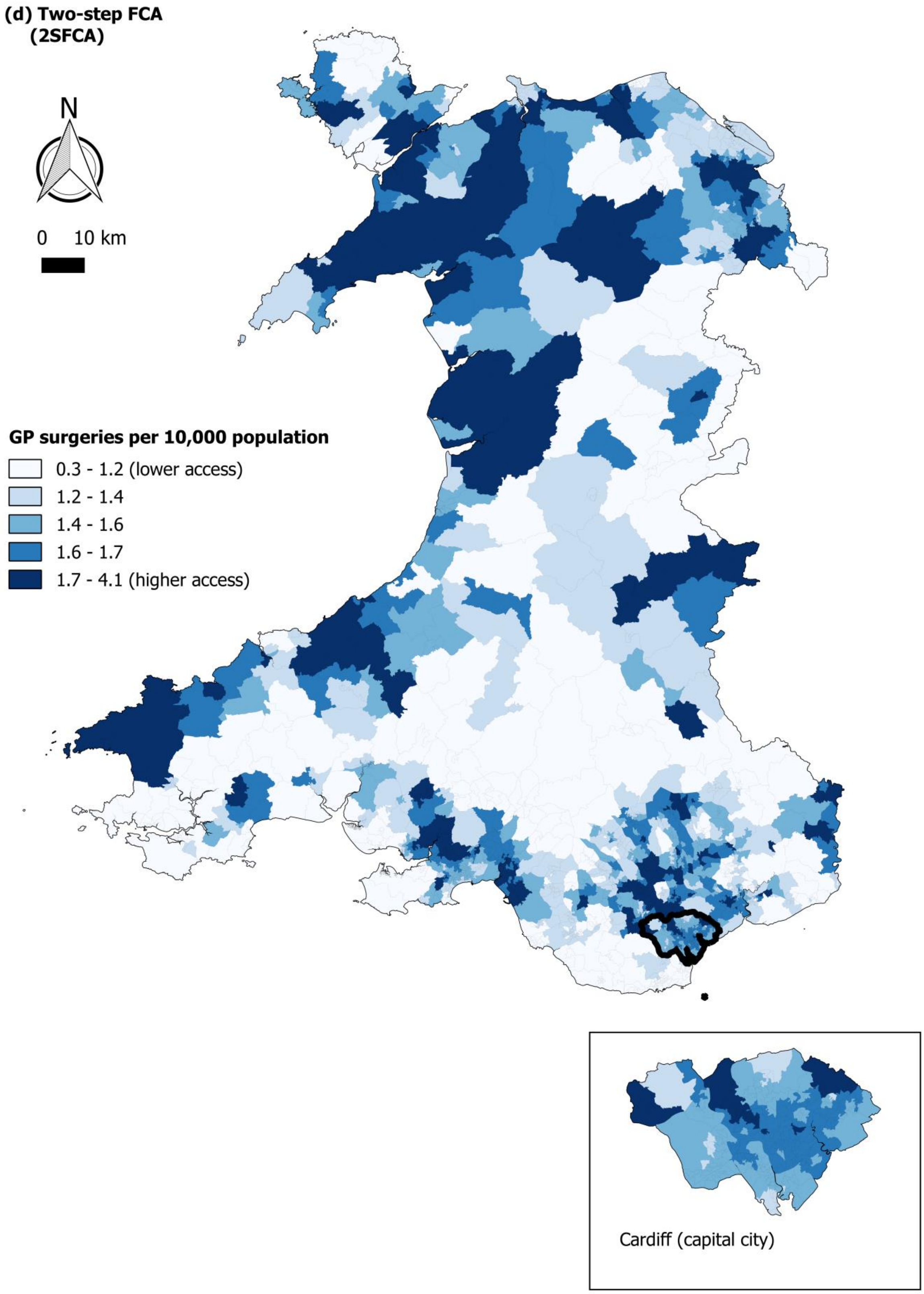


(a) Population-provider ratio (PPR)
N
0 10 km
GP surgeries per 10,000 population
No score
2.42 - 5.80 (lower access)
5.80 - 6.52
6.52 - 7.75
7.75 - 28.49 (higher access)
GP surgery site
Cardiff (capital city)


(b) Minimum travel time
N
0 10 km
Minutes to nearest GP surgery
0.001 - 0.634 (higher access)
0.634 - 1.118
1.118 - 1.720
1.720 - 2.899
2.899 - 19.146 (lower access)
Cardiff (capital city)

(c) Cumulative opportunity





(d) Two-step FCA
(2SFCA)
N
0 10 km
GP surgeries per 10,000 population
0.3 - 1.2 (lower access)
1.2 - 1.4
1.4 - 1.6
1.6 - 1.7
1.7 - 4.1 (higher access)
Cardiff (capital city)

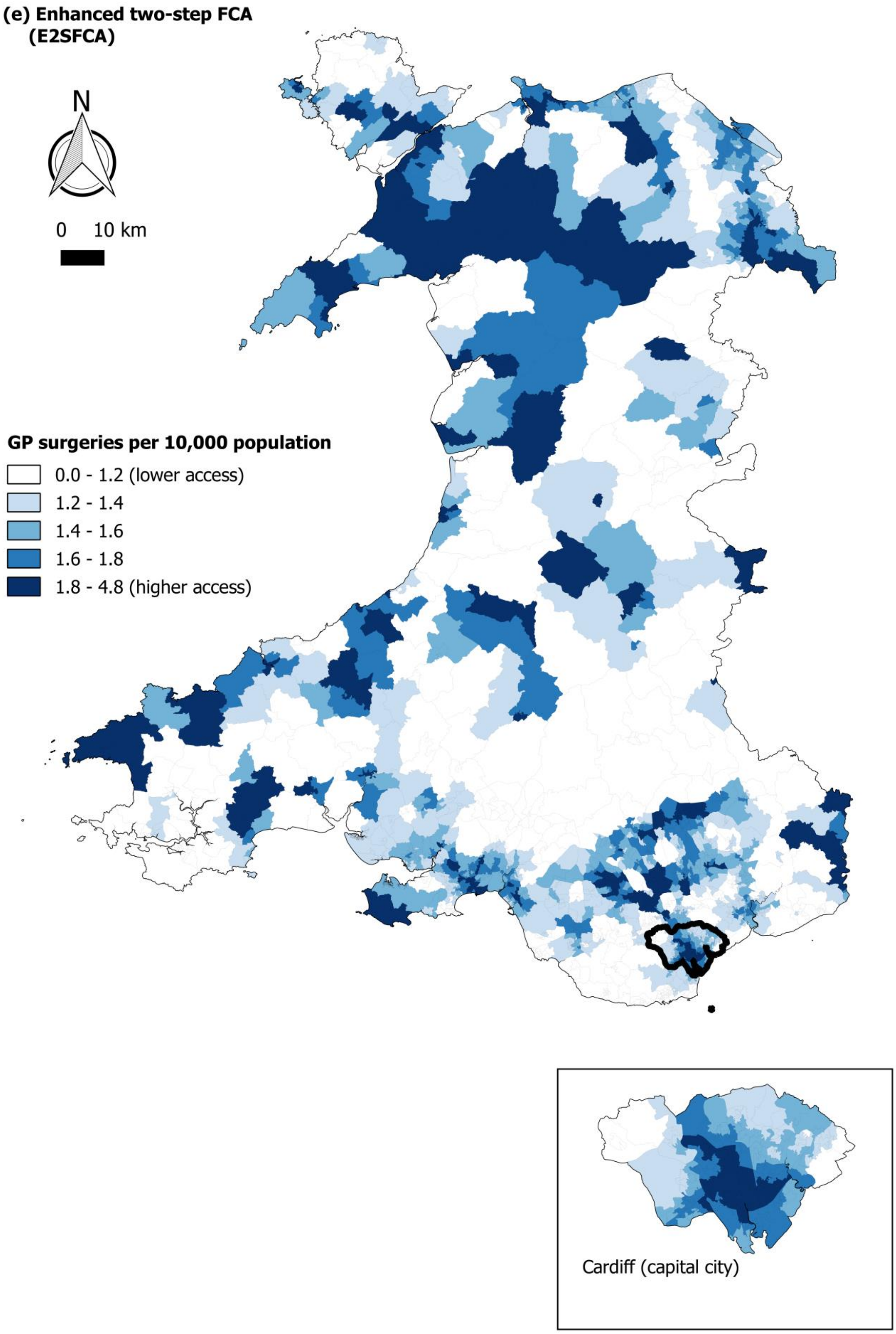


Figure 2: Spatial patterns in levels of access to GP surgeries in Wales according to PPR, minimum travel time, cumulative opportunity, 2SFCA, and E2SFCA methods

4.2. Service-specific associations between accessibility and area deprivation

An examination of service-specific associations between access scores and deprivation revealed further variation between the estimation methods (see Figure 3). For example, scores based on minimum travel time generally suggest a more linear association between deprivation and accessibility in Wales, with shorter travel times found within more deprived quintiles (i.e. 4 and 5). Similarly, scores based on cumulative opportunity also suggest a greater choice of services are available in the most deprived quintile (5), but also, in contrast, the least deprived (1); suggesting accessibility is greater at the extremes of deprivation. At odds with both these findings are patterns demonstrated by FCA-based approaches, which, for select services (e.g. post offices, primary and secondary schools), indicate an inverted U-shape pattern, whereby accessibility is shown to be highest in the middling deprivation quintiles (2-4). As expected, Figure 3 shows little variation in access score by deprivation quintile for the PPR metric. This is because the PPR-derived scores are highly skewed due to many of the LSOAs receiving a score of zero. Whilst subtle variations in the distribution of scores across the different service types are to be expected (for example, access to GP surgeries, pharmacies and food shops estimated with E2SFCA were found to be highest in the most deprived (5) and median (3) quintiles), variations between the metrics are reasonably consistent.

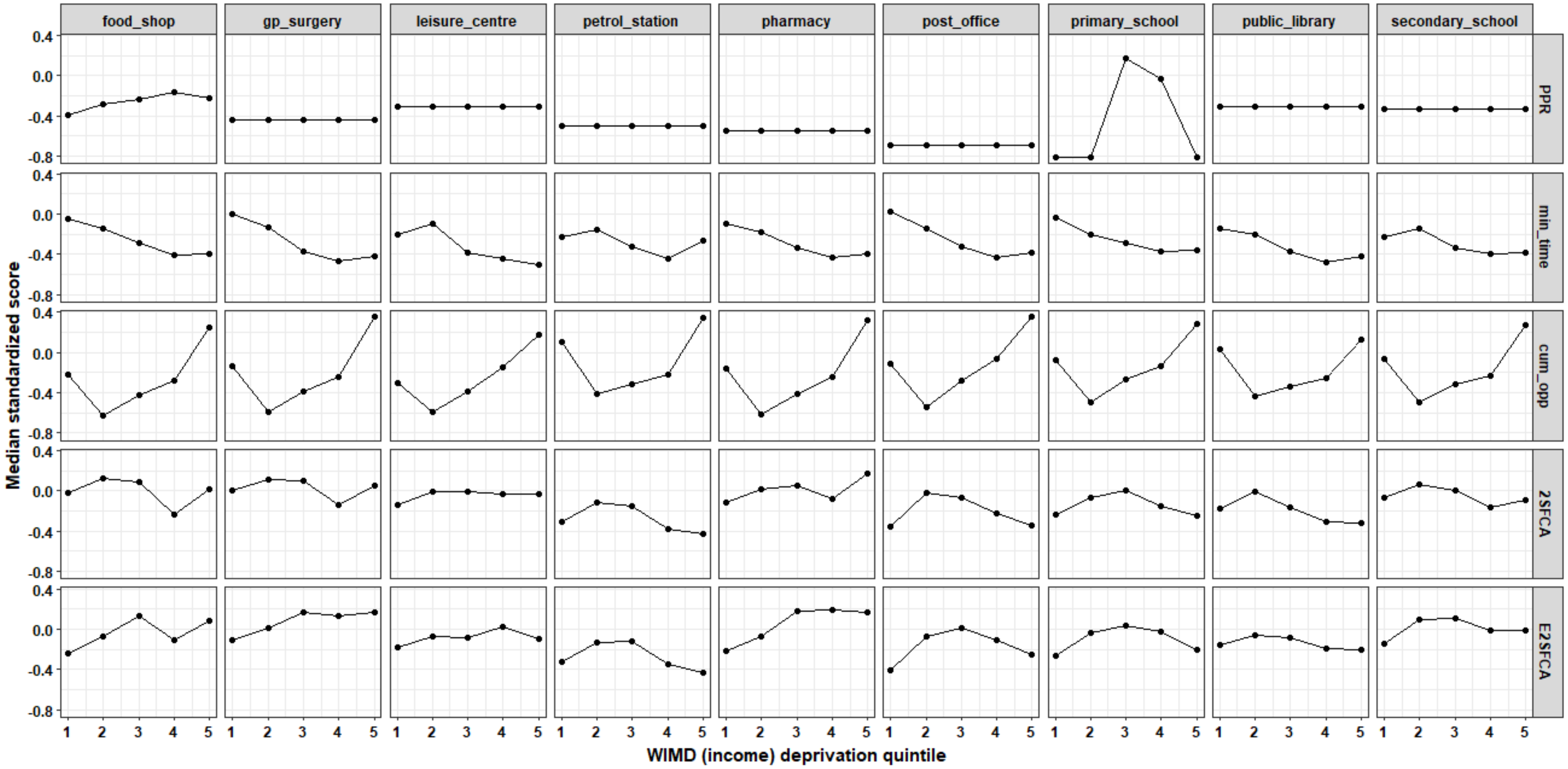


Figure 3: Service-specific comparison of standardized access scores by accessibility measure and deprivation quintile

4.3. Sensitivity analysis

A common criticism of FCA-based measures is the use of one catchment size to estimate levels of access. Indeed, several authors have suggested that this could lead to biased estimates if scores are computed over varying geographical contexts (McGrail and Humphreys, 2009). Therefore, to test the sensitivity of our findings, we examined the distribution of E2SFCA access scores by deprivation quintile (Figure 4) and rural-urban classification (Figure 5) at five, ten, fifteen and thirty minute thresholds. By doing so, we are thus able to highlight the extent to which catchment size impacts upon the socio-spatial distribution of services in Wales, as well as any variation across different rural-urban settings. As can be seen from Figure 4, we find little difference in socio-spatial patterns in E2SFCA accessibility scores between five, ten and fifteen minute catchment thresholds. Although these patterns are less consistent for the thirty-minute catchment, this is perhaps expected given that Wales is a relatively small country (approx. 20,000km^2) and evidence that almost every LSOA has ample access to each of these services well within a thirty-minute drive time (Welsh Government, 2015, p.9). Similarly, Figure 5 indicates that a relatively consistent pattern emerges regarding the distribution of E2SFCA scores across rural-urban geography for five, ten, and fifteen minute thresholds, suggesting that these trends are relatively stable irrespective of the adopted travel time threshold.

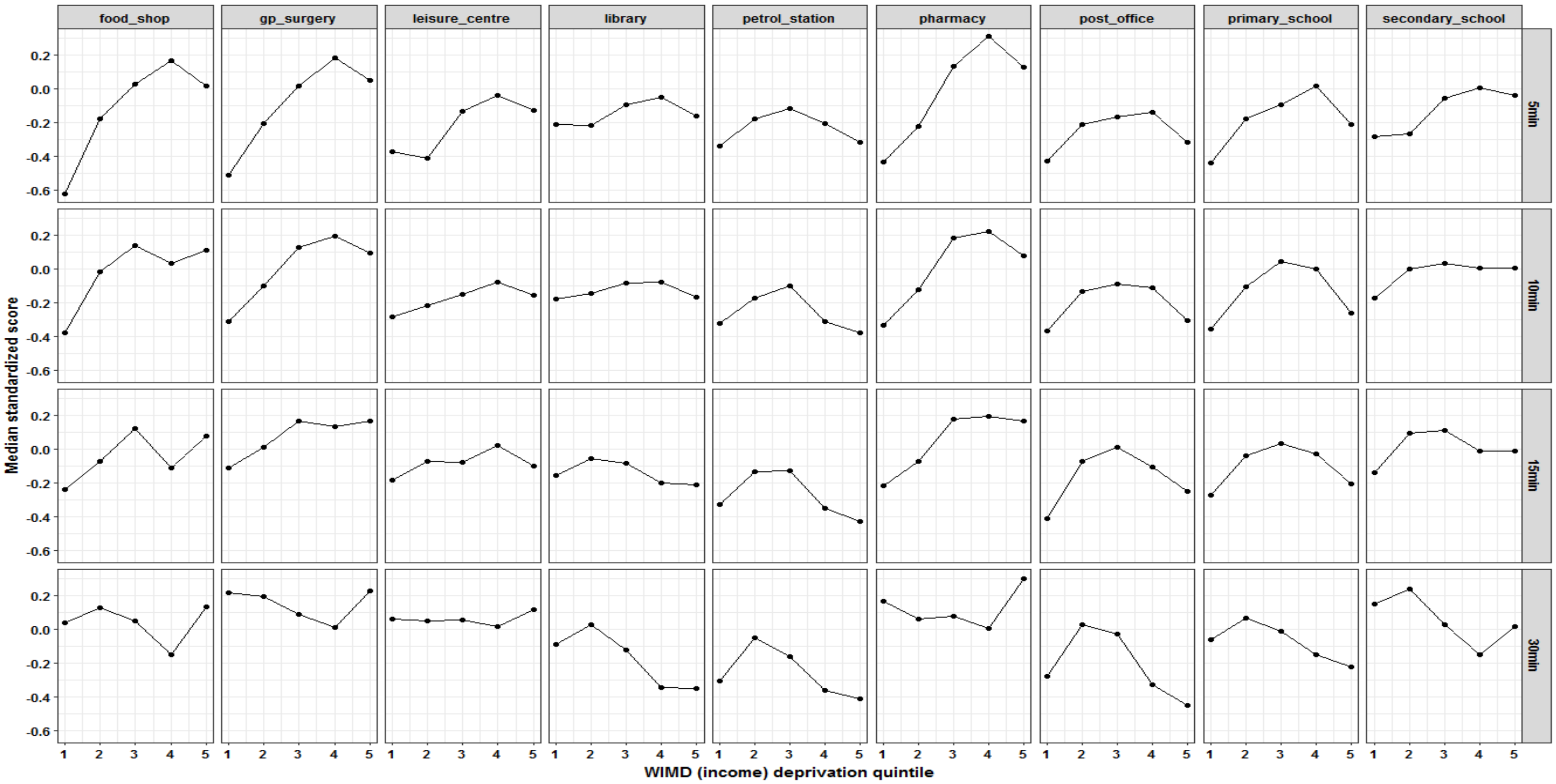


Figure 4: Service-specific comparison of socio-spatial distributions of E2SFCA scores by varying threshold distance

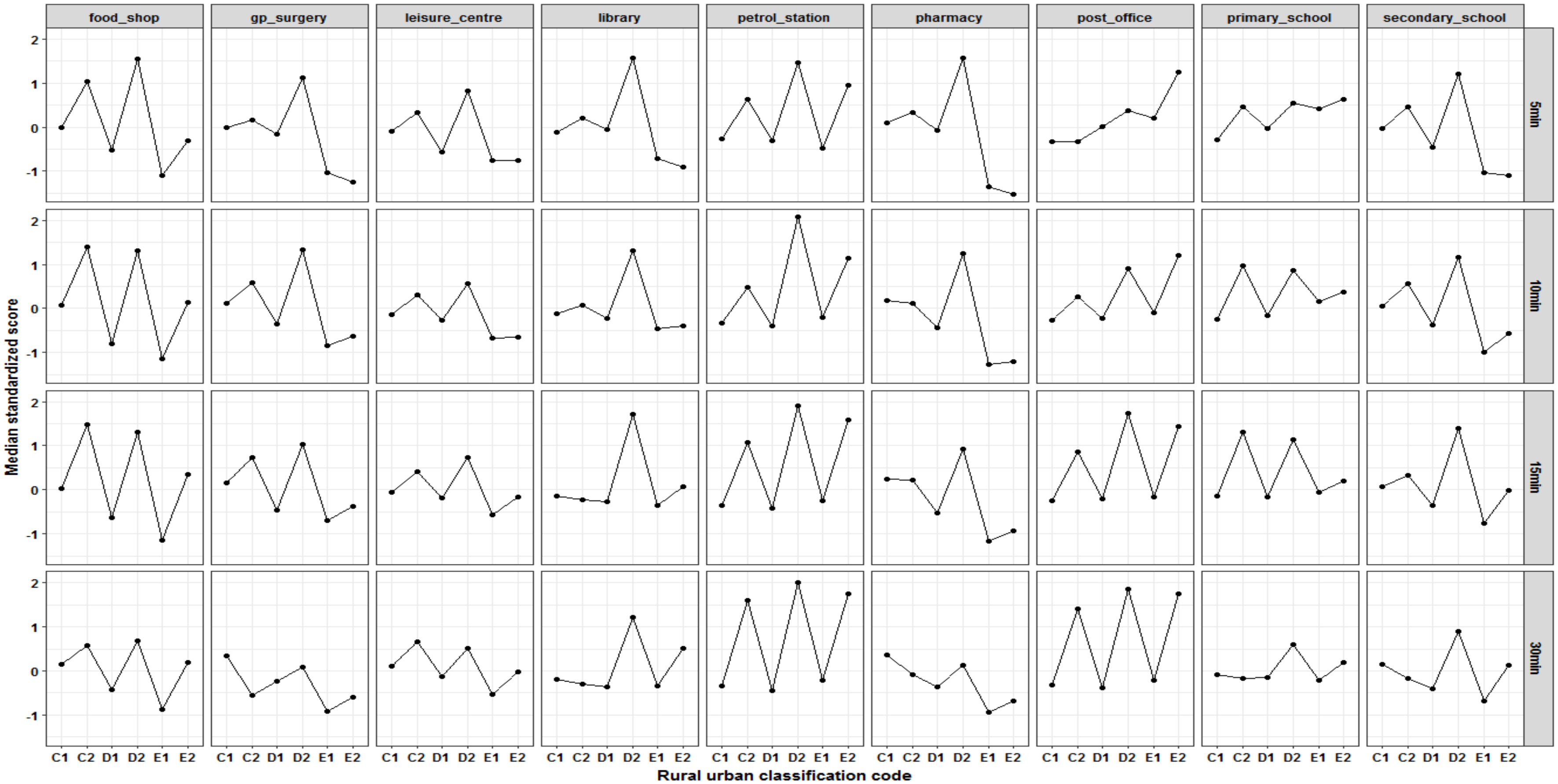


Figure 5: Service-specific comparison of rural-urban distributions of E2SFCA scores by varying threshold distance

5. Discussion

Approaches to accessibility measurement have evolved from using basic PPRs and travel cost metrics to more spatially complex gravity and FCA models owing to advancements in GIS technologies and the increased availability of high resolution data sets. With this greater choice of accessibility metric available to researchers, questions regarding the appropriateness and variability of these measures have become increasingly pertinent, and subsequently a number of studies have taken to investigating the sensitivity of estimated trends in geographical access to the approach taken (Talen and Anselin, 1998; Kim and Nicholls, 2016; Apparicio et al., 2007; Apparicio et al., 2017; Dewulf et al., 2013). This paper contributes to this body of work in two important ways: it is one of only a handful of studies to compare variations in estimated levels of accessibility obtained using spatially sophisticated FCA methods, which consider trade-offs between service supply and potential demand as well as travel cost and distance-decay effects (Luo and Wang, 2003; Luo and Qi, 2009), with patterns ascertained using ‘traditional’ metrics; and is the only national study, to our knowledge, that examines these patterns for multiple services and across deprivation gradients.

Three principal findings can be drawn from this study. Firstly, patterns of access revealed through the use of FCA-derived scores computed for small-areas of Wales were shown to differ substantially to those estimated using traditional metrics. Given the considerable differences in emphasis between FCA and traditional metrics, such dissimilarity between resultant access scores is not altogether unexpected. As intimated above, several authors have highlighted the volatility of spatial patterns in accessibility levels to contrasting approaches to its measurement. For example, Apparicio et al (2017) recently compared estimated patterns in access to health services in Montreal (Canada) calculated using various metrics (travel cost, FCA, and others), distances (Euclidean, Manhattan, network), and demand centre combinations. After a substantive analysis which included the computation of 336 separate indicators of accessibility, the authors identified the metric as being the most influential factor driving patterns of access, followed to a lesser degree by the choice of distance and representation of the demand centre. In our analysis, levels of accessibility to GP surgeries were estimated using PPR, minimum travel time, cumulative opportunity, 2SFCA and E2SFCA approaches. With the exception of PPRs, which were severely limited when applied at such a fine spatial scale, traditional access measures generally estimated higher levels of access in predominantly urbanised areas. Most likely this is the result of higher densities of services located within close proximity of urban demand centres and was most evident regarding access scores calculated based on a cumulative opportunity approach. In contrast, the interactive effects of supply capacity, demand volume and travel impedance within the 2SFCA and additional distance-decay implications within the E2SFCA, obtained much more nuanced patterns of access that were seemingly less driven by rural-urban geography.

Secondly, choice of accessibility metric was shown to influence the socio-spatial distribution of levels of access to a broad range of services in areas such as education, health and leisure. According to our findings, associations based on traditional measures tended to reveal a more linear relationship, indicating that greater levels of accessibility arise within more deprived areas, specifically in the context of higher service numbers and shorter travel times. However, this is in contrast to associations between accessibility and deprivation that are based on FCA techniques, which suggest such an association is distinctly non-linear and that, for some services at least, those areas lying between the extremes of deprivation appear to exhibit the highest accessibility scores. In general, this suggests that whilst residents living in more deprived areas may have access to a greater number of facilities in their immediate neighbourhood and require less travel to reach nearby services, these areas are adjudged to have much lower levels of access within an FCA framework after potential demand and distance-decay implications are also considered. Similarly, whilst levels of access based on a cumulative opportunity approach suggests a high proportion of services are also available in more affluent areas, relatively speaking, it is possible that many of these services are located close to the outer limit of the catchment threshold and therefore these areas are more access deprived when distance-decay effects are considered. Additionally, while our analysis highlighted how choice of method strongly influenced overall socio-spatial patterns in accessibility, the within-metric analysis displayed only marginal service-specific differences. Whilst detailed interpretation of these service-level patterns is beyond the scope of this study, a tentative explanation for any such variation could relate to service governance, i.e. whether a service is statutory (e.g. GP surgeries) or commercial (e.g. food shops), or governed centrally or locally.

Thirdly, we find no evidential base to support the contention that more deprived areas have worse access to community resources. This finding is consistent with other studies, both in the UK and abroad, which have generally found a less uniform association between levels of accessibility and area deprivation in varied contexts. Factors such as service type, ownership model (publicly or privately owned), geographical setting (urban or rural), and mode of transportation (such as travel by car, bus, bicycle, or foot) have each been shown to be important mediating influences on any such relationship. For example, a national study examining median travel times to a range of services in New Zealand revealed accessibility to be greater in most deprived relative to least deprived census blocks for 15 of the 16 services investigated, including recreation, education, and health-based facilities (Pearce et al., 2007). In Wales, an investigation into socio-spatial patterns in accessibility to sports facilities identified better access to public compared with private facilities in more deprived areas at certain scale and distance thresholds (Higgs et al., 2015). Patterns of access to physical exercise facilities in Scotland by deprivation quintile have also been revealed to be sensitive to both the mode of transportation used in the accessibility calculation and the geographical context of the study environment (Lamb et al., 2012). Specifically, within urban areas the number of facilities accessible within a 20 minute drive time was greater in more deprived relative to more affluent areas of Scotland by bus, compared with greater numbers of facilities accessible within the median relative to the affluent quintile by foot, and little difference between quintiles regarding travel by bicycle or car.

There are several limitations to the current study that must be acknowledged. Whilst a broad range of services were included within our analysis, it is still possible that patterns in accessibility to other services which were not included may differ. However, while our analysis has highlighted how choice of method strongly influenced overall socio-spatial patterns in accessibility, little service-specific differences were found. In this study, supply capacity was measured as the number of available provision sites (e.g. GP surgeries, primary schools, etc.) and demand volume using population counts. Where detailed provider or population data are available, it is possible that further refinements to both supply-side and demand-side variables within the FCA calculation, such as adjudging for classroom size and/or number of school-aged children when calculating levels of access to primary or secondary schools, for example, may potentially reveal greater service-specific variability regarding socio-spatial patterns in access. Moreover, although this is a national study possible border effects with England were not accounted for when computing potential accessibility. It is possible this could have led to lower estimations of accessibility for LSOAs situated along the Wales-England border for whom services in England may have been within their designated travel time thresholds – although this issue is less relevant for devolved services such as library provision. Finally, in this study we were only able to compare spatial patterns in potential levels of accessibility estimated using private transport (i.e. car) and were not therefore able to consider socio-spatial variations in access across different modes of transport, such as bus, bicycle, train, or foot, which have previously been shown to exhibit diverse patterns across different deprivation gradients (Ogilvie et al., 2011; Lamb et al., 2012).

6. Conclusion

This paper has demonstrated the extent to which associations between levels of access and socio-economic deprivation can differ depending on the accessibility metric adopted by comparing access scores computed for small-areas of Wales, UK based on traditional metrics with those derived using more advanced FCA methods – where the interactive effects of travel impedance, supply capacity and demand volume are considered. Overall, we found that service-specific patterns of access based on cumulative opportunity and minimum travel time measures were generally more suggestive of greater levels of access in more deprived areas – revealed by greater numbers of services within reasonable proximity of demand centres and altogether shorter travel times between services and potential users. In contrast, however, FCA derived patterns of access based on 2SFCA and E2SFCA methods were less indicative of a linear trend between access and deprivation, with evidence of greater levels of access in areas between the extremes of deprivation for certain services (such as primary and secondary schools, for example). This finding remained consistent after sensitivity testing of E2SFCA scores at multiple travel time thresholds. Additional sensitivity analysis of E2SFCA scores across rural-urban geography also confirmed the robustness of estimated trends to alternative catchment sizes.

It is important to re-emphasise that the findings of this study are in the context of Wales and may not reflect trends in other countries. Indeed, since the FCA model inputs will vary according to population size and location, data availability and quality, evidence of the presence and strength of an association between service accessibility and socio-economic deprivation may vary between studies that differ in scale of enquiry. Nonetheless, findings presented here of variable trends in spatial accessibility caused by contrasting approaches to measurement, and the potential implications thereof for understanding broader socio-spatial patterns of access, are important contributions to a growing body of literature calling for a wider array of measures to be included in studies concerned with examining spatial variations in accessibility to services.

A principal implication of this study from a policy context concerns the appropriateness of traditional measures of accessibility for highlighting spatial inequities in service provision, and the potential consequences in terms of targeting resources for particular areas. Indeed, it is possible that policies which necessitate drawing upon spatial patterns in geographical access, and which rely only on simplistic and, arguably, outdated measures, may prove ineffective at identifying those areas of greatest need. This is because such measures tend only to focus only on instances where physical access to services are poor and fail to consider implications arising from other contributory factors such as potential service demand or distance-decay effects. Moreover, while the focus of this study has been on implications born from contrasting approaches to measuring geographical accessibility, it is important to recognise that other factors besides proximity are also important when understanding how populations respond to variation in service provision (Humphreys et al. 1997). To this end, more research is needed with respect to service access which gives greater space to considerations of the implications of complex variations in human behaviour upon broader trends in patterns of access.

Acknowledgements

This paper is based on research supported by the Wales Institute of Social and Economic Research, Data and Methods (WISERD), funded by the Economic and Social Research Council (ESRC). WISERD is a collaborative venture between the Universities of Aberystwyth, Bangor, Cardiff, South Wales and Swansea (ESRC grant number: ES/L009099/1). We thank Sport Wales for the provision of data on the precise locations of all leisure centres in Wales. The views and opinions expressed in this paper are those of the authors alone.

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